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Imaging of Sports Injuries of the Lower Extremity

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KEYWORDS
• Imaging • Sports • Lower extremity • Musculoskeletal • MRI • Ultrasound

KEY POINTS
- Sports injuries of the lower extremity are common and affect multiple elements of the musculoskeletal system.
- Imaging allows for accurate diagnosis of sports injuries.
- Multiple imaging modalities, including radiography, ultrasound, MRI, and computed tomography, can play a role in evaluation of suspected lower extremity sports injury.

INTRODUCTION

Sports-related injuries are a typical indication for musculoskeletal imaging. Sports injuries can affect multiple components of the lower extremities, including bones, tendons, joints, ligaments, and muscles (Fig. 1). Injuries to athletes can occur during training or competitive play and can result from either acute trauma or chronic overuse [1]. Sports injuries affect players of all ages and genders. The phrase "boomeritis" specifically describes musculoskeletal injuries in the aging athlete [2]. With increasing participation in sports across ages and genders, knowledge of sports injuries is crucial for physicians [3].

According to the National Collegiate Athletic Association injury surveillance data for 15 sports across 16 years (1988–89 through 2003–04), more than 50% of all reported injuries were of the lower extremity [3]. Knee and ankle injuries accounted for most of the lower extremity injuries. Ankle ligamentous injury was the most common sports injury regardless of the type of sport and the level of play (ie, practice vs competitive game) [3]. Although anterior cruciate ligament (ACL) injury of the knee was significantly less common, its significance in sports medicine cannot be overlooked, given potential dire consequences and high rates of time loss for recovery. Regardless of the type of sport, player contact was the most common mechanism of injury [3].

Radiologists play an important role in the medical care of athletes, both through diagnosis of injuries as well as through evaluation of healing and assessment of recovery. Accurate recognition and appropriate image interpretation of lower extremity sports injuries is therefore crucial for the musculoskeletal radiologist. This article reviews imaging of common sports injuries of the lower extremity.

IMAGING TECHNIQUE

Radiography remains the first-line imaging modality for suspected injuries of the lower extremity [4]. Computed tomography (CT) and bone scintigraphy can be of additional value for evaluation of osseous injuries [5]. CT in particular may be useful for evaluation of healing of

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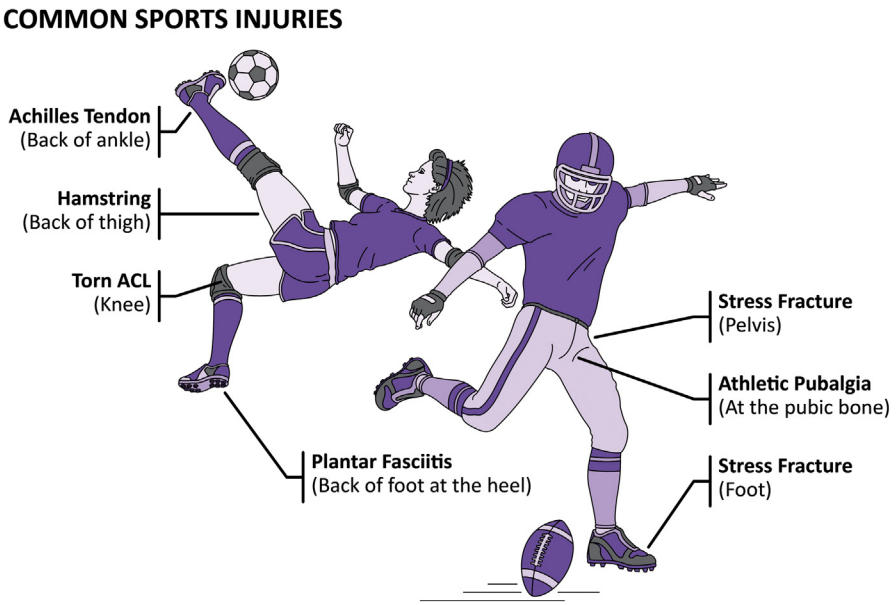

FIG. 1 Common sports injuries of the lower extremity. (*Courtesy of* D.C. Botos, Chicago, IL.)

osseous injury and for surgical planning [6]. Musculoskeletal ultrasound offers excellent evaluation of ligament and tendon injuries and can also be used to evaluate muscles, fascia, and nerves. Ultrasound has the advantage of allowing dynamic imaging and can readily assess the specific area of pain per the patient. Ultrasound also allows for comparison contralateral imaging and color Doppler evaluation as needed [4,7]. For evaluation of musculoskeletal soft tissue and joint pathology, MRI is the gold standard. Magnetic resonance (MR) arthrography, which entails injection of dilute gadolinium contrast medium into the joint before MRI, can improve visualization of intraarticular structures such as the labrum [4]. Advanced imaging techniques such as MR neurography may also be used for evaluation of nerves in sports injuries [8].

OSSEOUS SPORTS INJURIES

Potential sports injuries of bone include fractures and osseous contusions in the acute setting. Fracture patterns according to the orientation of the fracture line entail transverse, oblique, spiral, and comminuted (involving 2 or more fracture fragments) (Fig. 2). Fractures may be nondisplaced, displaced, and/or angulated [1]. A closed fracture implies intact skin, whereas an open fracture implies an associated skin wound often as a result of penetration by a fracture fragment [1].

In the chronic setting, stress reaction/stress fractures can occur as a result of overuse injury. Most of the stress fractures affect the lower extremity and are associated with a multitude of sports (Fig. 3). The tibia is the most commonly affected bone [5]. Tibial stress fractures can occur in either the transverse or longitudinal directions, with transverse fractures being more common. Posterior transverse fractures of the tibia are associated with long distance running [5]. Female runners are also at risk for stress fractures of the femur, typically within the femoral neck or shaft [5].

The most common osseous injury of the foot is a metatarsal fracture (Fig. 4A) [6]. In particular, fractures of the second and third metatarsal shafts are commonly seen in ballet dancers, the running athlete, and military personnel [7]. Fractures of the base of the fifth metatarsal are commonly seen in athletes of multiple sports, including basketball, American football, soccer, baseball, jogging, gymnastics, lacrosse, field hockey, and volleyball (Fig. 4B) [6]. Navicular stress fractures are reported in runners and basketball players [6].

Radiography is the first-line imaging modality for suspected acute fractures and should include a standard 3-view protocol (anteroposterior, oblique, and lateral). CT may also be obtained for surgical planning or to assess healing of a fracture [6]. Radiographic findings of stress fractures may not be identified until 3 to 4 weeks after injury onset and include periosteal

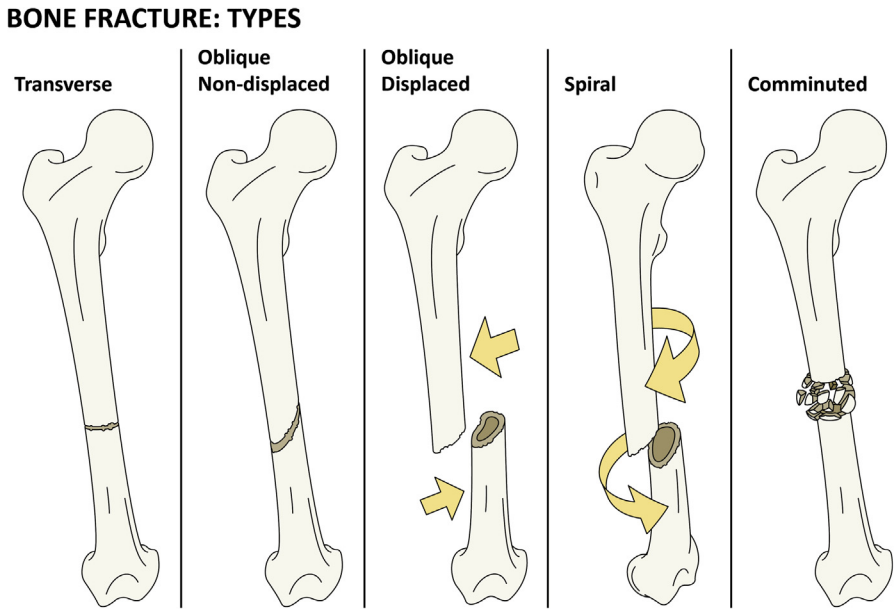

FIG. 2 Fracture types based on orientation of fracture line. (*Courtesy of* D.C. Botos, Chicago, IL.)

reaction, a fracture line, and reactive sclerosis [5]. MRI can detect stress fractures earlier than radiography due to visualization of bone marrow edema pattern within the affected bone (Fig. 5A) [5]. The Fredericson classification system is used to grade stress fractures of the tibia based on MR findings, progressing from periosteal edema to marrow involvement to cortical involvement (Figs. 5B, C) [5]. Acute fractures can also be assessed on MRI, which provides additional information regarding the integrity of adjacent soft tissues (Fig. 5D).

ARTICULAR SPORTS INJURIES

Sports injuries of joints include dislocation and subluxation in the acute setting and impingement syndromes and osteoarthrosis in the chronic setting [1]. Dislocation refers to complete separation of the bones involved in a joint such that the articular surfaces are no longer in contact. Subluxation is partial dislocation of the bones involved in a joint where the bones are shifted but the articular surfaces remain in partial contact. Both subluxation and dislocation injuries can result in damage to the complex structures forming the joint mechanism [1].

Pathology of the Lisfranc joint, in particular, is increasingly being recognized as a serious sports-related injury. Lisfranc injuries may be osseous, ligamentous, or both and can result in diastasis between the medial cuneiform and the base of the second metatarsal (Fig. 6). The Lisfranc joint is an important contributor to midfoot stability, and missed Lisfranc injuries can lead to long-term morbidity consequences [6].

Impingement syndromes can affect the hip, knee, and ankle joints. Within the hip, femoroacetabular impingement is a potential cause of hip pain, typically in pediatric athletes, and can lead to early osteoarthritis and labral tears [4]. Snapping hip syndrome is also common in adolescent athletes, typically ballet dancers and runners, and can be due to intraarticular versus extraarticular mechanisms [4,7]. Within the knee, infrapatellar impingement/Hoffa fat pad syndrome can lead to anterior knee pain in jumping athletes such as basketball and volleyball players (Fig. 7A). Hoffa fat pad syndrome is associated with patellofemoral maltracking disorder [4]. Ankle impingement syndromes can occur within the anterior/anterolateral joint recess often in the setting of prior trauma or in the posterior joint recess often in the setting of an os trigonum or Stieda process. Posterior ankle impingement is seen in athletes with repetitive forceful plantar flexion, such as ballet dancers and soccer players (Fig. 7B) [4].

Athletes are at risk for development of early osteoarthritis, as a result of overuse and repetitive joint injuries. Chondral injuries in the acute setting heal poorly due to the limited regenerative nature and repair capacity of articular cartilage [1]. In addition, specific sports injuries have a high association with development of posttraumatic osteoarthritis, including ACL rupture,

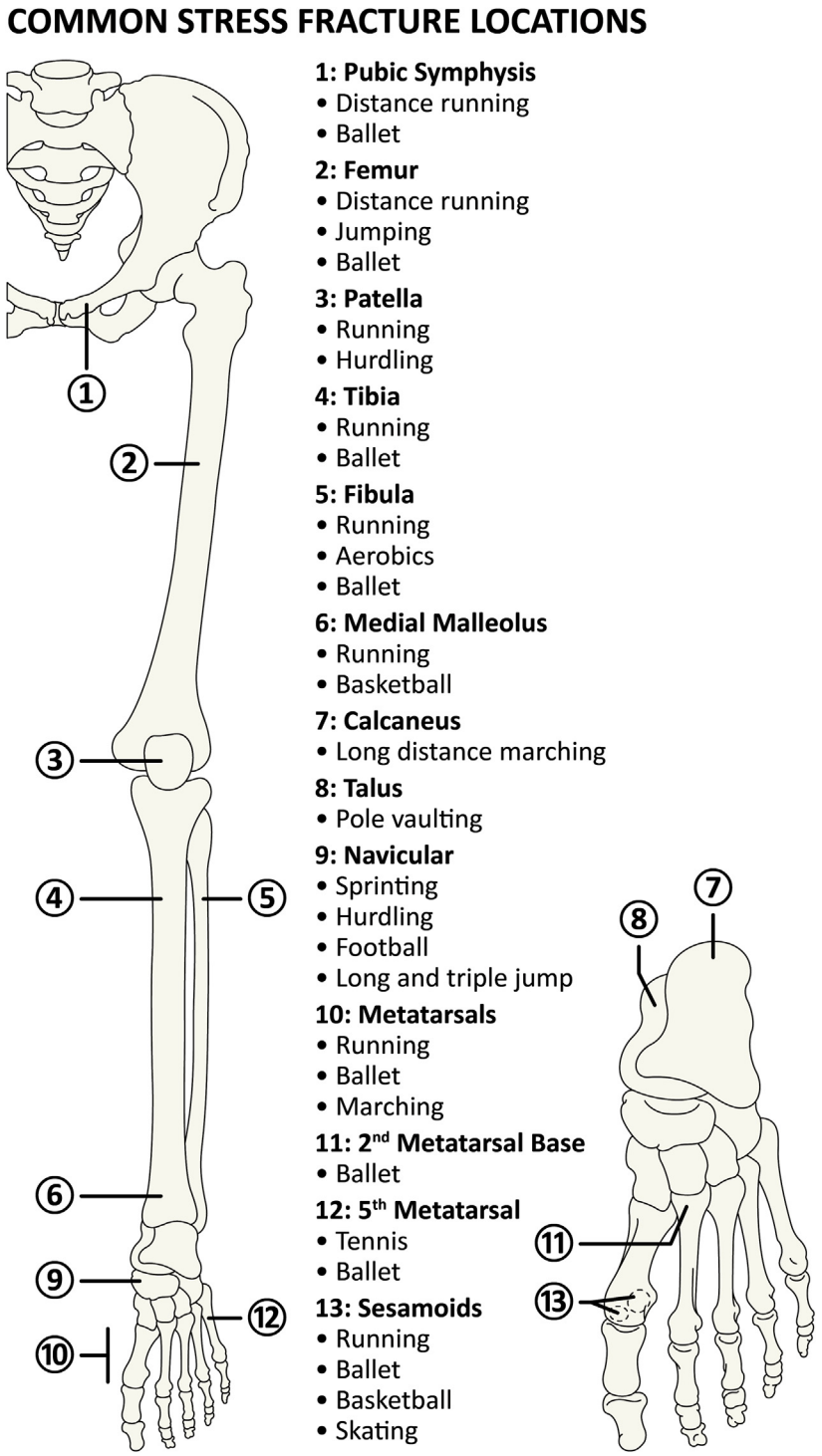

FIG. 3 Common stress fracture locations and associated sports. (*Courtesy of* D.C. Botos, Chicago, IL.)

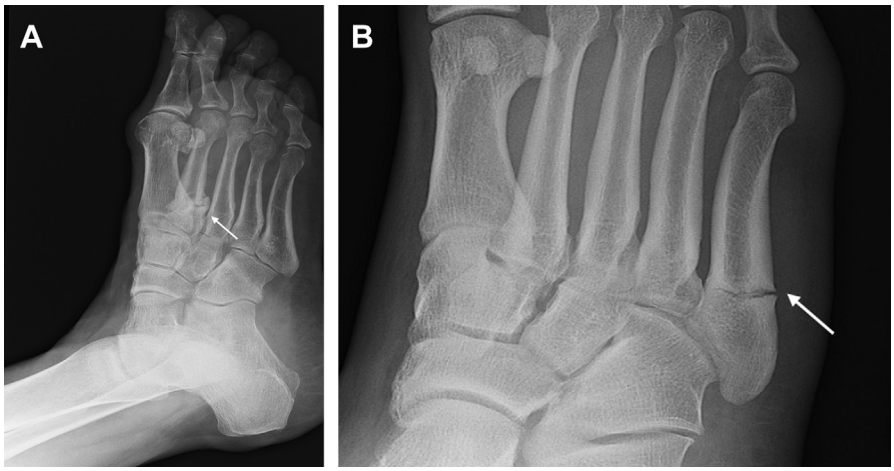

FIG. 4 Metatarsal fractures. (**A**) Oblique radiograph of the foot demonstrates a healing stress fracture at the base of the second metatarsal with callous formation (*arrow*). (**B**) Oblique radiograph of the foot demonstrates a transverse fracture at the base of the fifth metatarsal (*arrow*).

meniscal tear, patellar dislocation, and ankle instability. Kinematic, biological, and mechanical factors are all implicated in the development of posttraumatic osteoarthritis in athletes [9].

Radiography is the first-line imaging modality for acute joint injury and can readily identify subluxations and dislocations. Postreduction radiographs are recommended to assess for fracture [1]. In the case of Lisfranc injuries, weight-bearing radiographs should be obtained if possible to improve sensitivity. Initial radiographs can miss up to 20% of Lisfranc injuries, and hence, MRI is recommended in cases of

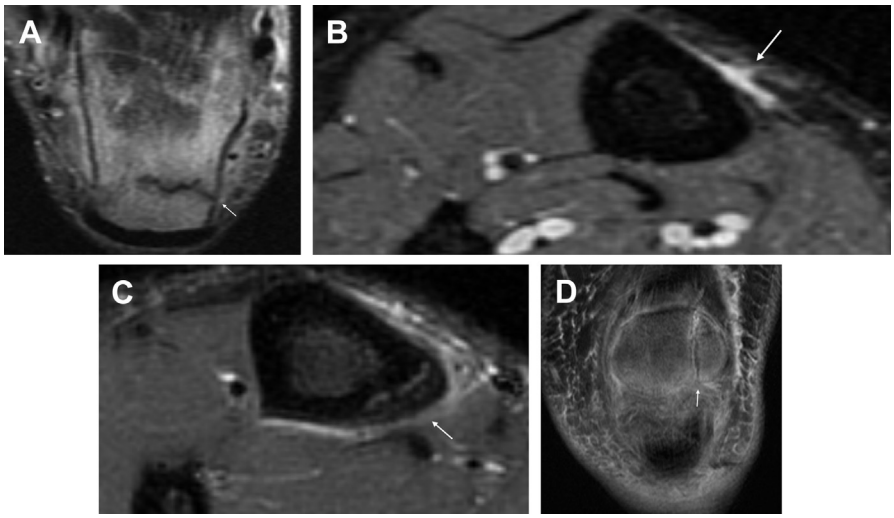

FIG. 5 Fractures on MRI. (**A**) Axial fluid-sensitive MRI of the ankle demonstrates a low signal intensity line within the calcaneus with surrounding bone marrow edema pattern (*arrow*), compatible with a stress fracture. (**B**) Axial fluid-sensitive MRI of the tibia demonstrates periosteal reaction along the anterior surface of the tibia (*arrow*), compatible with a low-grade stress reaction. (**C**) Axial fluid-sensitive MRI of the tibia demonstrates high-grade stress fracture of the tibia with fracture line visualized within the cortex and surrounding periosteal edema (*arrow*). (**D**) Coronal fluid-sensitive MRI of the knee demonstrates an acute vertical fracture of the patella with surrounding bone marrow edema pattern (*arrow*).

FIG. 6 Lisfranc injury. Anteroposterior radiograph of the foot demonstrates increased space between the first and second metatarsals (*arrow*) with lateral displacement of the second metatarsal with respect to the intermediate cuneiform, compatible with Lisfranc injury.

high clinical suspicion with negative or indeterminate radiographs [6]. In cases of suspected impingement syndrome, initial radiograph is often followed by MRI for further evaluation of the bone marrow and soft tissue structures [4]. Imaging evaluation of cartilage, both in the acute and chronic setting, is best performed with MRI (Fig. 8) [9].

LIGAMENTOUS SPORTS INJURIES

Ligaments typically span joints to provide stability and resist tensile loads. Acute ligamentous injury, colloquially referred to as "sprain," is common in athletes and can range in severity (Fig. 9). Grade 1 ligamentous injury entails disruption of some collagen fibers and presents with localized pain. Grade 2 ligamentous injury entails disruption of a considerable percentage of collagen fibers and presents with significant tenderness and moderate functional deficit. Grade 3 ligamentous injury entails complete disruption of the ligament with significant functional deficit and in some cases an audible pop at the time of injury [1].

Several ligaments within the lower extremity can be injured during sports. Injury of the ACL, in particular, is commonly assessed by sports medicine practitioners. Athletes who participate in jumping and pivoting sports such as soccer, basketball, and volleyball are at high risk for ACL tear. Female athletes are at higher risk for ACL tear than male athletes [10]. Most of the ACL injuries occur due to noncontact mechanisms, often associated with landing from a jump, changing direction, or sudden deceleration. Management options include ACL reconstruction, although the graft itself is susceptible to retear in athletes who return to play [10].

Ligamentous injury of the ankle is the most common sports injury [3], and most of the individuals heal naturally without consequence [11]. The anterior talofibular ligament is the most commonly injured ligament of the ankle, followed by the calcaneofibular ligament. The

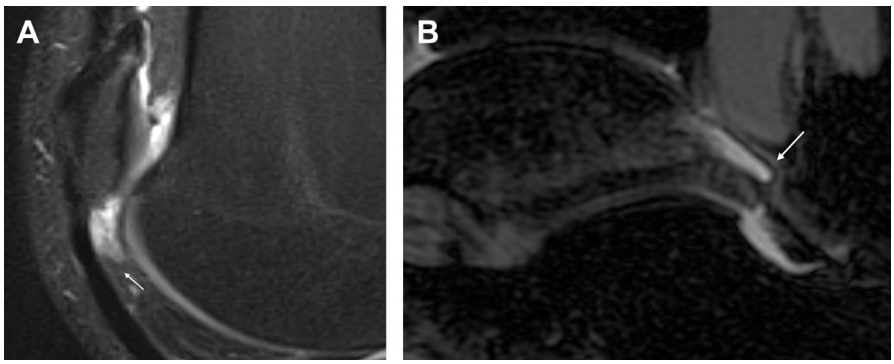

FIG. 7 Impingement syndromes. (**A**) Sagittal fluid-sensitive MRI of the knee demonstrates edema within superolateral Hoffa fat pad (*arrow*), compatible with fat pad impingement syndrome. (**B**) Sagittal fluid-sensitive MRI of the ankle demonstrates a Stieda process with bone marrow edema pattern (*arrow*), which suggests posterior ankle impingement.

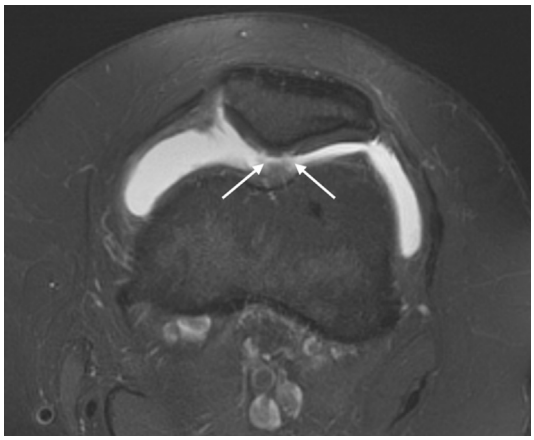

FIG. 8 Chondral pathology on MRI. Axial fluid-sensitive MRI of the knee demonstrates high-grade partial thickness chondral defects over the patella (*arrows*), eliciting mild synovitis.

lower syndesmotic ligaments can be injured with sufficient force and can result in ankle instability and rapidly progressive osteoarthritis if chronically torn [11]. Typically, the anteroinferior tibiofibular ligament is the first to be torn in lower syndesmotic injury, followed by the interosseous membrane [7]. The posterior syndesmosis is less commonly injured [11].

Evaluation of ligamentous injury is best performed with MRI (Fig. 10A). Ultrasound provides excellent visualization of some ligaments such as the anterior talofibular ligament and the anteroinferior tibiofibular ligament (Fig. 10B) [7,11]. An intact ligament with surrounding edema represents a grade 1 injury. Partial tear with disruption of some fibers and surrounding edema corresponds to a grade 2 injury. Complete tear of the ligament with no fibers seen in continuity and extensive surrounding edema entails a grade 3 injury [11]. In cases of ACL tear, MRI may demonstrate bone marrow edema pattern consistent with pivot shift mechanism of injury, specifically osseous contusions of the posterior aspect of the lateral tibial plateau, the middle lateral femoral condyle, and as a result of contrecoup force, the posterior aspect of the medial tibial plateau (Fig. 10C, D) [12]. In the chronic setting after ligamentous tear, the injured ligament may scar and hypertrophy, which can lead to impingement syndromes (Fig. 10E). Alternatively, the torn ligament may resorb, resulting in an attenuated or absent ligament that can lead to instability (Fig. 10F) [11].

MUSCULAR SPORTS INJURIES

Muscles represent the largest tissue group in the body and are commonly injured in sports [1,2]. Excessive tensile and/or shear forces on a muscle or muscle group

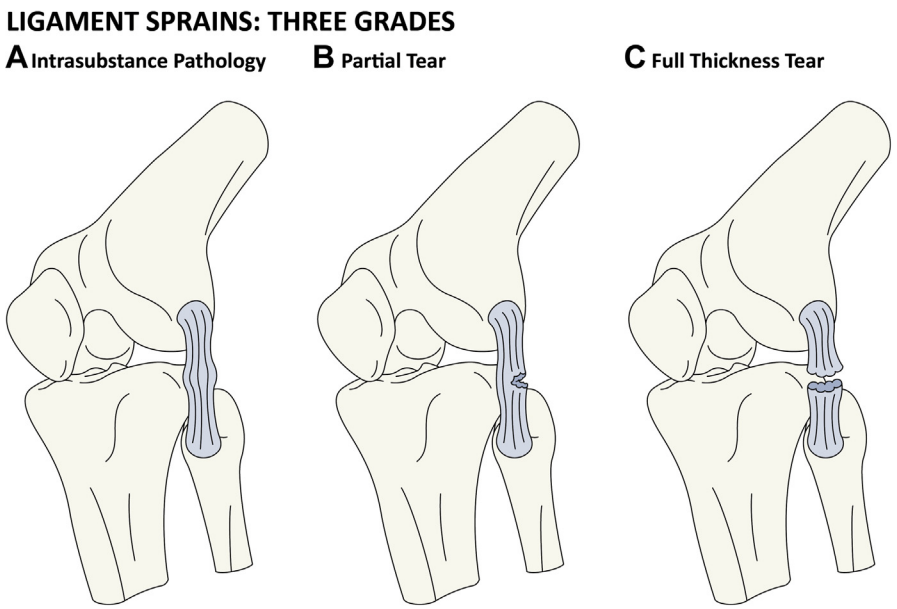

FIG. 9 Ligament Sprains. (*A*) Grade 1 sprain entails edema surrounding a ligament without discrete tear. (*B*) Grade 2 sprain entails partial thickness tearing with disruption of some fibers. (*C*) Grade 3 sprain entails complete tear of the ligament. (*Courtesy of* D.C. Botos, Chicago, IL.)

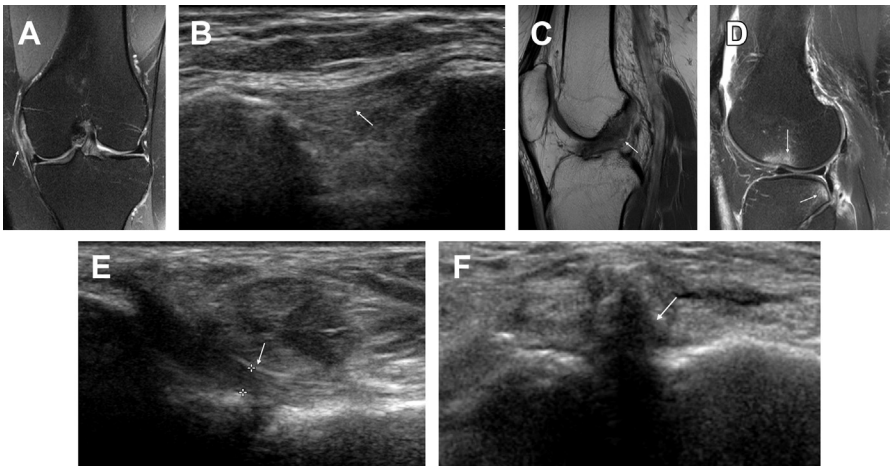

FIG. 10 Ligamentous injury on MRI and ultrasound. (**A**) Coronal fluid-sensitive MRI of the knee demonstrates moderate grade partial thickness tearing of the medial collateral ligament with adjacent soft tissue edema (*arrow*). (**B**) Ultrasound of the ankle demonstrates normal sonographic appearance of the anteroinferior tibiofibular ligament (*arrow*). (**C**) Sagittal proton density MRI of the knee demonstrates complete rupture of the anterior cruciate ligament (*arrow*). (**D**) Sagittal fluid-sensitive MRI of the knee demonstrates osseous contusions (*arrows*) compatible with pivot shift mechanism of injury. (**E**) Ultrasound of the ankle demonstrates thickening of the calcaneofibular ligament (*arrow* and *cursors*), compatible with chronic injury. (**F**) Ultrasound of the ankle demonstrates nonvisualization of the anterior talofibular ligament in the expected location (*arrow*), compatible with chronic tear.

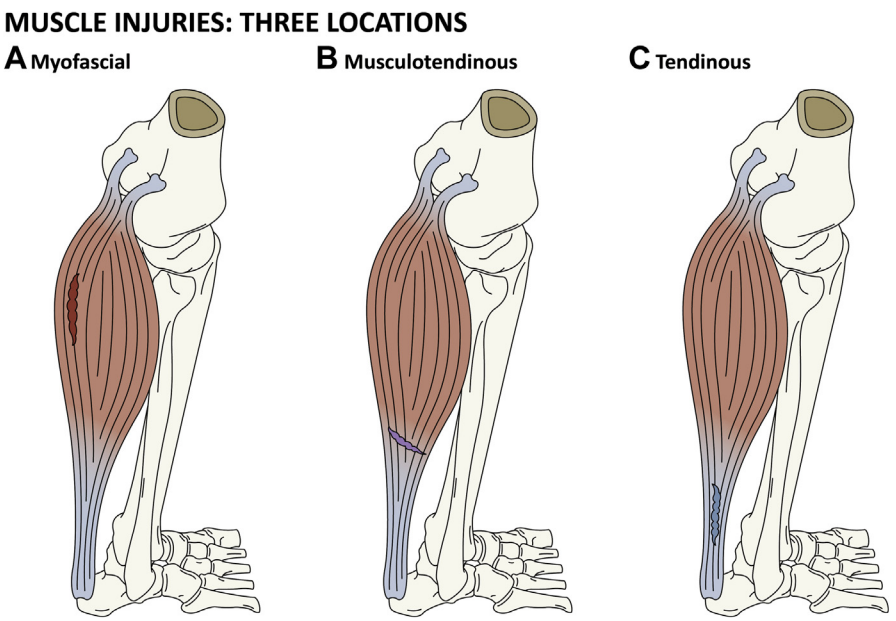

FIG. 11 Location of muscle injuries. (*A*) Myofascial injury is at the level of the muscle. (*B*) Musculotendinous injury is at the level of the muscle-tendon junction. (*C*) Tendinous injury is at the level of the tendon itself. (*Courtesy of* D.C. Botos, Chicago, IL.)

can result in a strain or tear, commonly within the hamstring, quadriceps, and gastrocnemius muscles in athletes [1,13]. Muscle injuries can occur at the myofascial level, at the myotendinous junction, or within the tendon itself (Fig. 11). Injuries at the musculotendinous junction are more severe and often lead to a delayed return to play [13]. Historically, muscle strains have been graded on a 3-tier classification scheme: grade 1 strain entails involvement of a small number of muscle fibers and a low-grade inflammatory response; grade 2 strain entails involvement of a greater number of muscle fibers and more severe clinical symptoms; and grade 3 strain entails a complete muscle tear with loss of function. More recently, however, muscle injury classification schemes have been expanded to include location and mechanisms of injury [1].

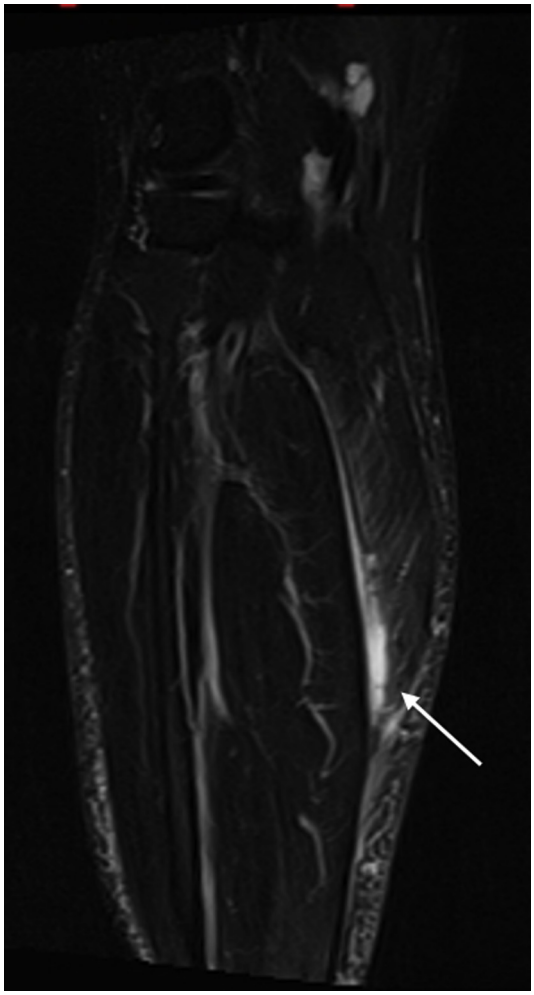

FIG. 12 Muscle injury on MRI. Coronal fluid-sensitive MRI of the tibia demonstrates a low-grade tear of the medial head of the gastrocnemius muscle with fluid accumulating between the gastrocnemius and soleus muscles (*arrow*).

A common mechanism of injury in sports is dorsiflexion of the ankle while the knee is extended, which results in a tear near the musculotendinous junction of the medial head of the gastrocnemius muscle (Fig. 12). Colloquially, this injury pattern is termed "tennis leg." Many patients with a gastrocnemius-soleus complex strain will develop a fluid collection between the gastrocnemius and soleus muscles. In a small percentage of patients, rupture of the plantaris muscle may occur [2]. Plantaris muscle rupture occurs at the myotendinous junction and can result in hemorrhage and fluid accumulating between the medial head of the gastrocnemius muscle and the soleus muscle [2].

Nonacute sports-related muscle injuries include muscle herniation and myositis ossificans. Muscle herniation entails protrusion of normal muscle through a defect in the overlying fascia, most often occurring in the lower extremity. Muscle hernia most frequently affects the tibialis anterior muscle. Other lower extremity muscles commonly seen in muscle hernia include the peroneal, gastrocnemius, soleus, and quadriceps muscles [7]. Myositis ossificans is intramuscular heterotopic ossification following muscular contusion injury. Myositis ossificans can be seen radiographically as early as 2 to 4 weeks after injury and is a self-limiting condition that is often managed conservatively [1].

Imaging evaluation of acute muscle injury is feasible with MRI. A grade 1 strain pattern entails minimal muscular disruption and feathery edema pattern within the muscle at the site of injury. A grade 2 strain pattern involves partial muscle disruption with edema and hemorrhage within the muscle and extending along the adjacent fascial planes. A grade 3 strain pattern entails complete muscle disruption with marked inflammation, hemorrhage, and muscle retraction [2]. Muscle hernia can be evaluated with both MRI and ultrasound, although ultrasound has the advantage of dynamic imaging, which may provoke/exacerbate the herniation [7].

TENDINOUS SPORTS INJURIES

Tendons transmit muscular contractile forces to bone to allow for motion. Given the high tensile strength of tendons, acute sports-related injury of a healthy tendon is rare [1] but may occur in the setting of a laceration with a sharp object [11]. Sports-related acute tendon injuries more commonly occur in the setting of underlying degeneration, often due to overuse [11]. For this

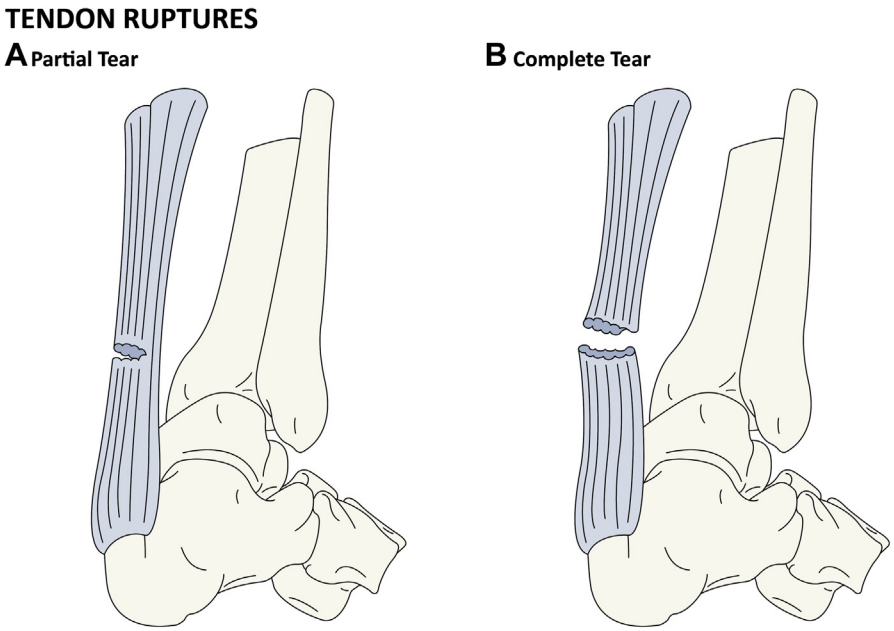

FIG. 13 Tendon tears. (*A*) Partial thickness tendon tear disrupts some but not all of the tendon fibers. (*B*) Full thickness tendon tear entails complete transection of the tendon. (*Courtesy of* D.C. Botos, Chicago, IL.)

reason, sports-related tendon injuries typically occur in older athletes or in elite athletes later in their career.

Tendon tears can be partial with involvement of some fibers or complete with retraction of the degenerated tendon stump resulting in a tendon gap [2] (Fig. 13). The most commonly ruptured tendon in the lower extremity in athletes is the Achilles tendon (Fig. 14A) [1]. The Achilles tendon bears extremely high loads during running and jumping and is often injured in runners, basketball players, volleyball

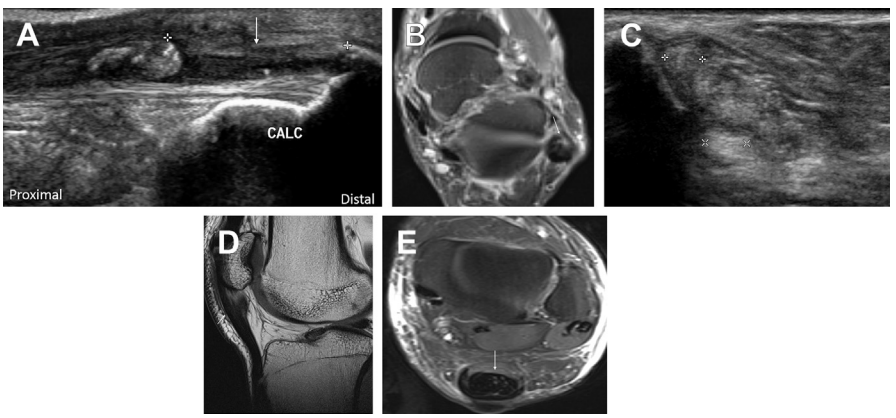

FIG. 14 Tendinopathy on ultrasound and MRI. (**A**) Ultrasound of the Achilles tendon demonstrates a high-grade tear of the posterior insertional fibers with a tendon gap (*arrow* and *cursors*). (**B**) Axial fluid-sensitive MRI of the ankle demonstrates a peroneus brevis split tear (*arrow*) and peroneus longus tendinosis. (**C**) Ultrasound of the ankle in a different patient demonstrates a split tear of peroneus brevis (*cursors*). (**D**) Sagittal proton density MRI of the knee demonstrates marked thickening and edema of the proximal patellar tendon (*arrow*), compatible with "jumper's knee." (**E**) Axial fluid-sensitive MRI of the ankle demonstrates marked thickening of the Achilles tendon with loss of concave anterior surface (*arrow*), compatible with tendinosis.

players, and racquet sport athletes [2]. Injuries to the Achilles tendon can occur at any location, including the proximal myotendinous region, the mid- or watershed zone, and the distal insertional region. "Haglund syndrome" refers to Achilles tendon pathology associated with retrocalcaneal and retro-Achilles bursitis [11].

The peroneal tendons are also prone to overuse injury in athletes. Pathology of the peroneal tendons includes tendinosis, tenosynovitis, tears including brevis split tear, and abnormal movement in the setting of superior peroneal retinaculum tear (Fig. 14B, C) [7,11]. The peroneus brevis and longus tendons are contained within the peroneal tendon sheath, which is intimately associated with the calcaneofibular ligament. During inversion injury, the peroneal sheath can be injured, which can allow for peroneal tendon dislocation and subluxation with dorsiflexion and eversion maneuvers [7,11].

Athletic injury of the extensor mechanism of the knee is common in jumping-related sports such as basketball and volleyball [7]. The rectus femoris, which spans 2 joints, is the most commonly injured component of the quadriceps femoris. The quadriceps femoris insertion at the patella is susceptible to overuse injury such as tendinosis and partial thickness tears as well as acute injury such as high-grade or complete tears [7]. Similarly, the patellar tendon is susceptible to overuse injury in athletes, and patellar tendinopathy is colloquially termed "jumper's knee" (Fig. 14D) [7].

Ultrasound or MRI can be used to assess tendon pathology. Tendinosis is observed as thickening and edema of the tendon, whereas a tear is diagnosed as a focal fluid signal cleft [7,11]. Tendinosis of the Achilles tendon is noted as thickening of the tendon that leads to a convex anterior surface as opposed to the normal concave appearance (Fig. 14E) [11]. Ultrasound can be used for dynamic evaluation of tendons, including assessment for peroneal tendon subluxation [7].

FASCIAL/APONEUROTIC SPORTS INJURIES

Sports injuries of lower extremity fascia and aponeurotic attachments can occur in athletes. The plantar fascia, or aponeurosis, is particularly susceptible to overuse injuries in runners as well as in athletes who participate in sports that increase the load of the plantar arch such as tennis and basketball [2]. Repetitive microtrauma to the plantar fascia origin can result in fasciopathy and chronic heel pain. The central cord of the plantar fascia is the most frequently injured component [7]. Pathology of the plantar fascia can be assessed with both MRI and ultrasound (Fig. 15A,

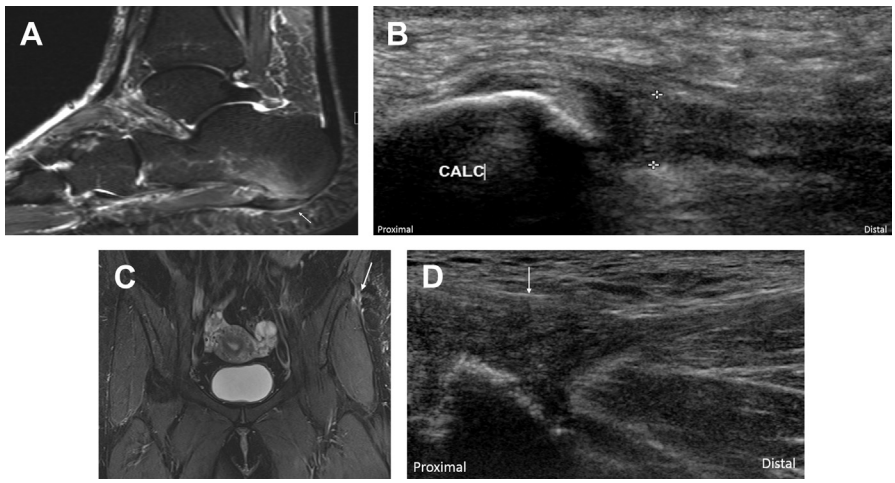

FIG. 15 Fascia/aponeurosis pathology on ultrasound and MRI. (**A**) Sagittal fluid sensitive MRI of the ankle demonstrates thickening and edema of the plantar fascia origin (*arrow*), compatible with plantar fasciitis. Reactive bone marrow edema pattern within the adjacent calcaneus is noted. (**B**) Ultrasound of the plantar fascia origin in a different patient demonstrates thickening and hypoechogenicity of the plantar fascia origin (*cursors*), compatible with plantar fasciitis. (**C**) Coronal fluid-sensitive MRI of the pelvis demonstrates partial thickness tearing of the left fascia lata attachment at the iliac crest with surrounding soft tissue edema (*arrow*). The right fascia lata attachment at the iliac crest is intact. (**D**) Ultrasound of the adductor longus demonstrates thickening and hypoechogenicity of the adductor longus attachment (*arrow*) at the pubic symphysis, compatible with athletic pubalgia.

B). Imaging findings include thickening of the fascia origin, partial thickness tears, and full thickness tears. Surrounding edema can be seen on MRI, and hyperemia may be present on Doppler ultrasound imaging [2,7].

The fascia lata attachment at the iliac crest is susceptible to overuse injury in athletes, particularly in female runners. The fascia lata, or deep fascia of the thigh, is a complex anatomic structure with contributions from the gluteal aponeurotic fascia and the iliotibial band at its lateral insertion at the iliac crest. Degeneration and tearing of the fascia lata attachment at the iliac crest can present with lateral hip pain and is readily diagnosed on MRI (Fig. 15C) [14].

Athletic pubalgia, also known as "sports hernia," is a syndrome of pubic symphyseal and groin pain in athletes. The most common cause is injury to the common aponeurosis of the rectus abdominis and adductus longus at the pubic symphysis. Pathology includes chronic overuse microtrauma, resulting in thickening and edema as well as partial thickness and acute full-thickness tears (Fig. 15D) [7,15]. Both MRI and ultrasound can visualize degeneration and tearing of the common aponeurosis and may detect irregularity of the underlying pubic symphysis cortex [7,15]. Findings of osteitis pubis can be detected on MRI and is common in athletes who participate in soccer, long-distance running, and hockey [15].

SUMMARY

Sports injuries of the lower extremity are common amongst athletes regardless of age and gender [2,3]. Multiple components of the musculoskeletal system can be injured in both the acute and chronic settings, including bones, joints, ligaments, muscles, tendons, and fascia. Prognosis varies based on the type and severity of injury. A variety of imaging modalities are available to assess musculoskeletal sports injury, including radiography, CT, ultrasound, and MRI. Knowledge of imaging findings of sports injury on all modalities is crucial in providing adequate medical care of athletes.

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